In the Claims

This listing of claims will replace all prior versions, and listings, of claims in the application:

Listing of Claims

1. (Original) A timing error estimation apparatus for multi-carrier systems, comprising:

a timing offset compensator for receiving a current symbol in a frequency domain after taking an N-point Discrete Fourier Transform (DFT) and compensating said current symbol for an effect of timing offset with a timing offset prediction value; and

a timing error estimator coupled to said timing offset compensator to take a timing compensated version of said current symbol on pilot subcarrier locations, for calculating a timing error value based on a function of a phase tracking value, a channel response of each pilot subcarrier, transmitted data on each pilot subcarrier, and said timing compensated version of said current symbol on said pilot subcarrier locations.

2. (Original) The apparatus as recited in claim 1 wherein said timing error value of said current symbol, $\tau_{\varepsilon,i}$, is defined by:

$$\tau_{\varepsilon,i} = \tau_{E,i} - \tau_{P,i}$$

where

subscript i denotes a symbol index,

$\tau_{E,i}$ is a measure of timing offset of symbol i,

$\tau_{P,i}$ is said timing offset prediction value of symbol i, and

$\tau_{\varepsilon,i}$ represents said timing error value of symbol i.

3. (Original) The apparatus as recited in claim 1 wherein said timing error estimator calculates said timing error value by the following function:

$$\tau_{\varepsilon,i} = -\frac{N}{2\pi} \frac{\mathrm{Im}\left\{ e^{-j\phi_{T,i}} \sum_{m=1}^{N_{SP}} p_m R'_{i,p_m} \left(H_{p_m} X_{i,p_m} \right)^* \right\}}{\sum_{m=1}^{N_{SP}} p_m^2 \left| H_{p_m} \right|^2}$$

where

superscript * denotes complex conjugation,

$\mathrm{Im}\{\cdot\}$ denotes the imaginary part of a complex number,

$\phi_{T,i}$ denotes said phase tracking value of symbol i,

N_{SP} is the number of said pilot subcarriers,

p_m denotes a pilot subcarrier index, for m =1, 2, . . . , N_{SP},

H_{p_m} denotes said channel responses of pilot subcarrier p_m,

X_{i,p_m} denotes said transmitted data on pilot subcarrier p_m of symbol i,

R'_{i,p_m} denotes said timing compensated version of the ith symbol on pilot subcarrier location p_m, and

$\tau_{\varepsilon,i}$, denotes said timing error value of symbol i.

4. (Original) The apparatus as recited in claim 1 wherein said timing offset compensator is employed to compensate the i th symbol on pilot subcarrier location p_m using said timing offset prediction value of the i th symbol and provides as output said timing compensated version of the i th symbol on pilot subcarrier location p_m .

5. (Currently Amended) A timing tracking apparatus for multi-carrier systems, comprising:

a parameter table for storing a plurality of loop parameters;

an nth-order tracking loop for computing a timing offset prediction value for a next symbol based on a timing error value of a current symbol, [[said]] a timing offset prediction value of said current symbol and said loop parameters [[that]], which are retrieved from said parameter table for said current symbol; and

a timing synchronizer for generating a shift amount of a DFT window for said next symbol according to said timing offset prediction value of said next symbol, in which said DFT window shift amount is equal to zero if said timing offset prediction value of said next symbol is within a predetermined range;

wherein said timing synchronizer applies said DFT window shift amount to align the DFT window and further starts an inhibit interval if said shift amount is not equal to zero, and provides said DFT window shift amount for further subtraction from said timing offset prediction value of said next symbol upon completion of said inhibit interval.

6. (Original) The apparatus as recited in claim 5 wherein said timing synchronizer sets said DFT window shift amount to zero for said next symbol during said inhibit interval, except upon the start of said inhibit interval.

7. (Currently Amended) The apparatus as recited in claim 5 wherein said nth-order tracking loop computes a timing offset tracking value and a period offset tracking value for said current symbol based on said loop parameters regarding said current symbol, ~~[[said]]~~ a period offset tracking value of a preceding symbol, said timing offset prediction and said timing error values of said current symbol, and yields said timing offset prediction value for said next symbol by summing said timing offset and said period offset tracking values of said current symbol.

8. (Original) The apparatus as recited in claim 5 wherein said nth-order tracking loop is a second-order tracking loop modeled with a set of recursive equations, as follows:

$$\tau_{T,i} = \tau_{P,i} + \mu_{\tau,i}\tau_{\varepsilon,i}$$

$$v_{T,i} = v_{T,i} + \mu_{v,i}\tau_{\varepsilon,i}$$

and

$$\tau_{P,i+1} = \tau_{T,i} + v_{T,i}$$

where

subscript i denotes a symbol index,

$\tau_{T,i}$ and $v_{T,i}$ denote a timing and period offset tracking value of symbol i,

respectively,

$\mu_{\tau,i}$ and $\mu_{v,i}$ denote said loop parameters of the i th symbol for $\tau_{T,i}$ and $v_{T,i}$,

respectively,

$\tau_{P,i}$ denotes said timing offset prediction value of the i th symbol,

$\tau_{p,i+1}$ is said timing offset prediction value of symbol i+1,

$v_{T,i-1}$ is said period offset tracking value of symbol i-1, and $\tau_{\varepsilon,i}$, said timing error value of the i th symbol, is given by:

$$\tau_{\varepsilon,i} = \tau_{E,i} - \tau_{P,i}$$

where $\tau_{E,i}$ is a measure of timing offset of the i th symbol.

9. (Original) The apparatus as recited in claim 8 wherein said second-order tracking loop receives as input a frequency offset estimate and calculates an initial value for said period offset tracking value as follows:

$$v_{T,i} = -N' \cdot \frac{\hat{f}_d}{f_c}, \; i = -1$$

and

$$N' = \frac{T'}{T_s}$$

where

$\hat{f}_d$ denotes said frequency offset estimate,

f_c denotes a nominal carrier frequency,

T' denotes a symbol interval,

T_s denotes a sampling period,

$v_{T,i}$ denotes said period offset tracking value of symbol i, and

$v_{T,-1}$ denotes said initial value for $v_{T,i}$.

10. (Original) A timing offset compensation apparatus for multi-carrier systems, comprising:

a timing offset compensator for receiving a current symbol in a frequency domain after taking an N-point Discrete Fourier Transform (DFT) and compensating said current symbol for an effect of timing offset with a timing offset prediction value;

a timing error estimator for taking a timing compensated version of said current symbol on pilot subcarrier locations and calculating a timing error value for said current symbol based on a function of a phase tracking value, a channel response of each pilot subcarrier, transmitted data on each pilot subcarrier, and said timing compensated version of said current symbol on said pilot subcarrier locations; and

a timing tracking unit for receiving said timing error value of said current symbol to generate said timing offset prediction value and a shift amount of a DFT window for a next symbol.

11. (Original) The apparatus as recited in claim 10 wherein said timing error value of said current symbol, $\tau_{\varepsilon,i}$, is defined by:

$$\tau_{\varepsilon,i} = \tau_{E,i} - \tau_{P,i}$$

where

subscript i denotes a symbol index,

$\tau_{E,i}$ is a measure of timing offset of symbol i,

$\tau_{P,i}$ is said timing offset prediction value of symbol i, and

$\tau_{\varepsilon,i}$ represents said timing error value of symbol i.

12. (Original) The apparatus as recited in claim 10 wherein said timing error estimator calculates said timing error value by the following function:

$$\tau_{\varepsilon,i} = -\frac{N}{2\pi}\frac{\mathrm{Im}\left\{e^{-j\phi_{T,i}}\sum_{m=1}^{N_{SP}} p_m R'_{i,p_m}\left(H_{p_m}X_{i,p_m}\right)^*\right\}}{\sum_{m=1}^{N_{SP}} p_m^2\left|H_{p_m}\right|^2}$$

where

superscript * denotes complex conjugation,

$\mathrm{Im}\{\cdot\}$ denotes the imaginary part of a complex number,

$\phi_{T,i}$ denotes said phase tracking value of symbol i,

N_{SP} is the number of said pilot subcarriers,

p_m denotes a pilot subcarrier index, for m =1, 2, . . . , N_{SP},

H_{p_m} denotes said channel responses of pilot subcarrier p_m,

X_{i,p_m} denotes said transmitted data on pilot subcarrier p_m of symbol i,

R'_{i,p_m} denotes said timing compensated version of the i th symbol on pilot subcarrier location p_m, and

$\tau_{\varepsilon,i}$, denotes said timing error value of symbol i.

13. (Original) The apparatus as recited in claim 10 wherein said timing offset compensator is employed to compensate the ith symbol using said timing offset prediction value of the ith symbol and provides as output said timing compensated version of the ith symbol, $R'_{i,k}$, where subscript k denotes a subcarrier index.

14. (Original) The apparatus as recited in claim 10 wherein said timing tracking unit comprises an nth-order tracking loop to generate said timing offset prediction value for said next symbol by computing a timing offset tracking value and a period offset tracking value of said current symbol.

15. (Original) The apparatus as recited in claim 14 wherein said timing tracking unit further comprises a timing synchronizer to receive said timing offset prediction value of said next symbol from said nth-order tracking loop, generate said DFT window shift amount for said next symbol, and further start an inhibit interval if said shift amount is not equal to zero, in which said DFT window shift amount is applied to align the DFT window and is provided for further subtraction from said timing offset prediction value upon completion of said inhibit interval.

16. (Original) The apparatus as recited in claim 10 wherein said timing tracking unit comprises:

a parameter table for storing a plurality of loop parameters;

an nth-order tracking loop for computing said timing offset prediction value for said next symbol based on said timing error value of said current symbol, said timing offset prediction value of said current symbol and said loop parameters that are retrieved from said parameter table for said current symbol; and

a timing synchronizer for generating said DFT window shift amount for said next symbol according to said timing offset prediction value of said next symbol, in which said DFT window shift amount is equal to zero if said timing offset prediction value of said next symbol is within a predetermined range;

wherein said timing synchronizer applies said DFT window shift amount to align the DFT window and further starts an inhibit interval if said shift amount is not equal to zero, and provides said DFT window shift amount for further subtraction from said timing offset prediction value upon completion of said inhibit interval.

17. (Original) The apparatus as recited in claim 16 wherein said timing synchronizer sets said DFT window shift amount to zero for said next symbol during said inhibit interval, except upon the start of said inhibit interval.

18. (Original) The apparatus as recited in claim 16 wherein said nth-order tracking loop is a second-order tracking loop modeled with a set of recursive equations, as follows:

$$\tau_{T,i} = \tau_{P,i} + \mu_{\tau,i}\tau_{\varepsilon,i}$$

$$v_{T,i} = v_{T,i} + \mu_{v,i}\tau_{\varepsilon,i}$$

and

$$\tau_{P,i+1} = \tau_{T,i} + v_{T,i}$$

where

subscript i denotes a symbol index,

$\tau_{T,i}$ and $v_{T,i}$ denote a timing and period offset tracking value of symbol i,

respectively,

$\mu_{\tau,i}$ and $\mu_{v,i}$ denote said loop parameters of the ith symbol for $\tau_{T,i}$ and $v_{T,i}$,

respectively,

$\tau_{P,i}$ denotes said timing offset prediction value of the ith symbol,

$\tau_{p,i+1}$ is said timing offset prediction value of symbol i+1,

$v_{T,i-1}$ is said period offset tracking value of symbol i-1, and $\tau_{\varepsilon,i}$, said timing error value of the ith symbol, is given by:

$$\tau_{\varepsilon,i} = \tau_{E,i} - \tau_{P,i}$$

where $\tau_{E,i}$ is a measure of timing offset of the ith symbol.

19. (Original) The apparatus as recited in claim 18 wherein said second-order tracking loop receives as input a frequency offset estimate and calculates an initial value for said period offset tracking value as follows:

$$v_{T,i} = -N' \cdot \frac{\hat{f}_d}{f_c},\ i = -1$$

and

$$N' = \frac{T'}{T_s}$$

where

$\hat{f}_d$ denotes said frequency offset estimate,

f_c denotes a nominal carrier frequency,

T' denotes a symbol interval,

T_s denotes a sampling period,

$v_{T,i}$ denotes said period offset tracking value of symbol i, and

$v_{T,-1}$ denotes said initial value for $v_{T,i}$.

20. (Original) The apparatus as recited in claim 16 wherein said timing tracking unit further comprises a flip-flop that receives as input said timing offset prediction value of said next symbol and provides as output said timing offset prediction value for said current symbol.